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Aiding airlines for the benefit of whom? An applied game-theoretic approach

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A B S T R A C T

In the face of a significant exogenous shock, government intervention may be required at the level of an industry in order to preserve the market. By employing a game engineering approach, we develop a model to test the potential impact of varying types of bailout schemes on network oriented industries facing such a shock. Investigating the European aviation market, served by both legacy and low-cost carriers, we assess whether the forms of aid offered during the Covid-19 pandemic may lead to changes in market equilibrium outcomes over the coming years. Airlines choose the size of their fleet, schedule and airfares across the network and compete for market share. The social welfare analysis suggests that the European Commission has likely distorted competition in the aviation markets by allowing Member States to provide different types of rescue packages. In addition, we show that the most efficient solution would have been to coordinate state aid, preferably in the form of time-limited loans. Furthermore, the approach could be applied as a screening tool by governments when considering bailout requests. Its application ex-ante allows policymakers to assess the likelihood of taxpayers receiving a return on their investment.

1. Introduction

This paper investigates whether government support programs provided to network oriented firms are likely to affect competition and overall welfare. The recent pandemic has sparked renewed discussions regarding the use of state aid to rescue financially distressed companies. Over the last decades, policymakers have been discussing the challenging decision of whether to allow firms to file for bankruptcy or to save them using taxpayers' money under specific circumstances. The approach has tended towards the latter choice (Jackson et al., 2020) when an entire market is faced with an exogenous shock. Bailing out a firm consists of an ex-post measure that acts to provide financial relief to a company that is facing a liquidity crisis in order to accelerate recovery. During national or international emergencies, regulators may be urged to rescue a firm or an entire industry. Academics and decision-makers have often viewed bailouts as unfair aid instruments, resulting from failures in the capital markets that prevent firms from accessing lines of credit. The most frequently adopted fiscal stimuli include the provision of grants, deferral of taxes, loan issuances or government equity injections. The latter instrument is rarely applied to bail out firms due to the distorting effect induced by government participation as a firm stakeholder (DG Competition, 2008). However, in the specific event that a firm cannot sustain the burden of additional debt, it may rely on equity instruments as a bailout method in place of bankruptcy (Megginson & Fotak, 2021). The government aid scheme should be carefully evaluated and designed to prevent moral hazard behaviours whilst ensuring adequate government remuneration. The bailout of the US auto industry in 2008 has proven that government intervention could result in an effective stimulus for a distressed industry and that governments may recover the money borrowed (Goolsbee & Krueger, 2015). An optimal bailout policy should be applied systematically to all firms in the industry, preventing large companies from pursuing risky practices due to the protection offered by the "too big to fail" paradigm (Bianchi, 2016). Despite several crises over the past decades, including the financial crisis of 2008, an optimal bailout mechanism has not yet been defined. Another crucial aspect when defining bailout policy is to identify only the liquidity-constrained firms that will be capable of repaying the aid over time. However, the process of distinguishing such companies is difficult, particularly under the time pressures caused by a sudden crisis.

Recently, several heterogeneous industries have required state

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support, ranging from the automobile sector to the banking system. Among these distressed industries, the airline sector has shown continuous vulnerability to shocks due to its high debt exposure. Multiple exogenous events have affected the aviation industry, including the 9/11 terrorist aggression, the 2008 financial crisis and epidemics such as SARS in 2003 and the recent Covid-19 outbreak. Regulators have the task of weighing the benefits of bailing out airlines and preserving connectivity for economic and societal benefits, with the risks of endangering taxpayers' money and distorting competition. This decision process is made more difficult due to the specific characteristics of the airline industry, which include sovereignty, safety and military concerns as well as multiple business models that compete in a subset of markets. Another layer of complexity is imposed by the lack of cooperation among policymakers in civil aviation, leaving each country with the possibility of enacting autonomous measures. These sovereign decisions generate fragmented policies that potentially result in market inefficiencies and competitive distortions, both regionally and internationally. For example, over the last decade, there has been much discussion over the policies of the Middle East as compared to those of the US and Europe (Tretheway & Andriulaitis, 2015).

The Covid-19 pandemic offers a convenient case study to apply and validate our model specification in the context of the European Union. Specifically, the Coronavirus pandemic has disrupted the entire world economy. Governments enforced national lockdowns which severely affected economic activities. As a consequence of these measures, the aviation industry was one of the more severely affected sectors, with thousands of flights cancelled and billions of dollars in lost revenue. Forecasts estimate that the industry will take years to fully recover and reach the traffic levels offered before the outbreak of the virus. In 2020, the entire industry faced an overall loss of profits of more than 80%, from both domestic and international flights (Pearce, 2020), which has been estimated at approximately $372 bn in 2020 (ICAO, 2020). Furthermore, prior to the pandemic, most airlines were in distress due to their leveraged financial positions. The debt level, higher than market investment grade (ICAO, 2020), discouraged potential investors and reduced access to traditional lines of credit during the pandemic. After the lockdowns were lifted, the demand for air travel has shown slow signs of recovery, for the most part, sustained by domestic markets (Andreana, Gualini, Martini, Porta, & Scotti, 2021). This has highlighted the absence of a sharp rebound in passenger demand, suggesting that a full recovery will take several years. Since the beginning of the pandemic, 34 legacy and low-cost operators have already filed for bankruptcy (CAPA, 2021). Given the difficulties and bleak projections for the aviation industry, liquidity remains an issue and many carriers face the risk of bankruptcy. European governments, using public resources, re-wrote the rules and adopted several measures to permit the provision of financial aid, including grants, loans, recapitalization and tailored hybrid instruments. Although a public bailout of a Member State requires the authorisation of the European Commission, each country decided on the type of financial aid and its size. This characteristic raises concerns that Member States have chosen a financial instrument in order to increase the market power of domestic carriers at the expense of fair competition (de Jong, Behrens, van Herk, & Verhoef, 2019).

1.1. Aviation literature

Bankruptcies and government support for distressed airlines have long been a topic of academic interest (Borenstein & Rose, 1995; 2003; Ciliberto & Schenone, 2012a; 2012b). Borenstein & Rose (1995) analyze pricing strategies of airlines under Chapter 11 protection, using an econometric approach. Starting from the industry claim that bankruptcy-protected carriers are harmful to the entire industry due to price-cutting behaviours, they prove that small price reductions occur before any government intervention. They show that protected airlines experience a decline in market share, despite the lower fares, induced by declines in demand for distressed carriers which are perceived as lower-quality service providers. In Borenstein & Rose (2003), the authors extend the investigation to the impact of airlines filing for Chapter 11 protection on aggregate air service. They find that carriers under protection tend to reduce their operations, which is particularly significant for midsize airports. The possible bankruptcy of an airline with a relatively high share of flights at the airport would result in a severe contraction of air service. Ciliberto & Schenone (2012b), following the previous works of Borenstein & Rose (1995, 2003), explore the impacts induced by a competitor airline facing bankruptcy filing and protection on the industry. The results of their work highlight how network carriers affected by bankruptcy decrease airfares and offered capacity. In addition, Ciliberto & Schenone (2012a), focus on vertical differentiation by investigating the variation in service quality as defined through flight delays, cancellations and aircraft age, of airlines under Chapter 11 protection. They do not find any significant improvement in the quality of the service after the bankruptcy restructuring.

Airline competition and network strategies have been widely discussed in the operations research literature since the beginning of the 1990s (Adler, 2001; 2005; Adler, Brudner, & Proost, 2021; Dobson & Lederer, 1993; Hansen, 1990; Hansen & Liu, 2015; Hendricks, Piccione, & Tan, 1999; Hong & Harker, 1992; Vaze & Barnhart, 2012; Wang, Zhang, Dai, & Lee, 2022). Among these works, Hansen (1990) defines a non-cooperative framework in which airlines compete in frequency, keeping prices fixed, in a hub-and-spoke network. Market share was defined by a discrete choice model that accounts for passenger preferences. A point of quasi-equilibrium was found that resembled the state of the market. Hong & Harker (1992) proposed a two-stage market model that addresses oligopolistic competition. In this framework, airlines compete over gate allocations, fares, itineraries and landing rights, assuming the carriers' networks as given. They model exogenous and endogenous slot allocation decisions. Dobson & Lederer (1993) analyze airline competition in terms of airfares and scheduled flight frequencies by developing a two-stage game framework in which the equilibrium is derived considering one type of passenger and symmetric hub-spoke networks. Under the assumption of a fixed plane size and no traffic originating from the hub, they develop a heuristic and find a solution for a small network, proving the feasibility of more realistic large-scale implementation potential. Hendricks et al. (1999) investigate the effects of different behaviours between competing airlines in a hub-and-spoke network, by developing a two-stage game. Under the assumptions of infinite seat capacity and no shared itineraries, they show that aggressive competition results in a monopoly outcome. In this case, the monopolistic airline is driven to develop a hub-spoke network. On the other hand, in a duopoly equilibrium in which both carriers select a hub-spoke structure, neither airline has an advantage over the competitor. Adler (2001, 2005) investigates competition between hub-spoke networks using a two-stage, non-cooperative game. Following this specification, in the first stage airlines select their network and in the second stage, they compete in frequencies and prices, taking into account multiple passenger types. We learn that the number of competitors in a market is a direct function of demand levels, leading to oligopolistic markets and hub fortresses. Vaze & Barnhart (2012) develop a game-theoretic competition model for service frequency when airport slots are constrained. They show that, given the airport capacity requirements, a profitable schedule can be obtained while accommodating all passenger demand. Following the modelling formulation proposed in Vaze & Barnhart (2012), Wang et al. (2022) develop an equilibrium model to address airline frequency competition at slot-constrained airports, whilst considering balanced flows. They prove that a pure strategy Nash equilibrium may not always exist but under mixed strategies, alliances are likely to form and increase airline profitability. Hansen & Liu (2015) design two models able to predict competition between two symmetric airlines when they differ only in the structure of frequency competition. By implementing a nested logit specification, they found consistent results between their analytical framework and empirical evidence. For a comprehensive review of game-theoretic models applied to transportation markets, we refer the reader to Adler et al. (2021).

The impact of airline decisions on social welfare, in the context of competition, has been addressed in several publications (Adler, Pels, & Nash, 2010; Schipper, Nijkamp, & Rietveld, 2007). Schipper et al. (2007) simulate the impact of airline competition on social welfare, focusing on the Amsterdam-Maastricht corridor. They develop a two-stage model in which airlines set frequencies and subsequently prices. They find welfare gains when low-cost carriers enter a deregulated market, due to lower fares and higher service frequencies. Adler et al. (2010) develop a dynamic game in which airlines compete between themselves and also against high-speed rail operators, in terms of fares and service frequency. They solve the resulting non-linear maximization problem, applied to the European Union context and assess the overall impact of infrastructure investments on social welfare.

The literature analyzing the impact of the pandemic support mechanisms on airline competition is still scant (Abate, Christidis, & Purwanto, 2020; Zhang & Zhang, 2021). Abate et al. (2020) propose an exploratory analysis of the impact of direct government support measures on the airline industry. They describe the different forms of aid available to airlines, examining the effect on air connectivity and the environmental dimension. Their work suggests that government bailout decisions were mainly motivated by connectivity preservation which ignores pre-existing policies to limit the impact of aviation environmental externalities. Zhang & Zhang (2021) discuss government interventions on airline bankruptcies, with an application to Virgin Australia. The authors highlight that the preferred funding channel should be the private market, but warn of the potential social costs resulting from the failure to reach such an agreement in the private market.

1.2. *Bailout mechanisms literature*

The optimal approach to bailing out a distressed firm has been extensively discussed in the academic literature. Most of these studies theoretically investigate the impact of bailout mechanisms, specifically on the banking and financial systems (Bianchi, 2016; Chari & Kehoe, 2016; Diamond & Rajan, 2002; 2005; Gorton & Huang, 2004; Pandolfi, 2022; Philippon & Skreta, 2012; Wollmann, 2018). Diamond & Rajan (2002) caution about the risks associated with a partial rescue of the banking system, highlighting the potential for systemic default arising from aggregate liquidity constraints and excessive demand. Gorton & Huang (2004) develop a theoretic model that includes moral hazard behaviour. The results of their model suggest that a well-defined government bailout is able to eliminate moral hazard and obtain an efficient social outcome. Bianchi (2016) finds that the only way to efficiently bail out an industry during a crisis, when hazardous behaviours may arise, is to systemically rescue all the distressed firms in the sector. Adopting a different perspective, Chari & Kehoe (2016) build their work on the intuition that bailouts are the source of inefficiencies rather than a cure. In their dynamic model, an optimal mechanism is derived that allows governments to exert stringent, ex-ante authority and commitment.

Liquidity shortage and insolvency can lead to contagion between endangered and healthy firms, increasing the risk of a systemic meltdown. This effect is modelled in Diamond & Rajan (2005). The authors develop an equilibrium model able to incorporate the interaction between insolvency and scarce liquidity as the cause of contagion in the banking system. They show that government intervention, whether in the form of liquidity injection or recapitalization, could prevent a systemic collapse if the institution financed remains solvent. If the rescued bank is not able to ensure sufficient liquidity, it would trigger an excess of new recapitalization, spreading the contagion across healthy institutions. Adopting an operations research approach, Klages-Mundt & Minca (2022) investigate the optimal intervention to a shock in a specific type of financial network. They apply approximation algorithms to the NP-hard problem of a network subject to an intervention scheme and show that it is possible to bail out a set of firms and maximize value.

The design of an optimal government mechanism to bail out an industry, considering an outside market, has been addressed in Philippon & Skreta (2012). The results obtained from their theoretical model show the impossibility of improving investment schemes using cost-less interventions and the ability to define an ex-ante, optimal intervention by assessing borrowing rates outside the market. They also highlight the irrelevancy of the size of the intervention, the efficiency of the debt-like bailout and that there is no linkage between the cost of implementing the intervention and the private market. Wollmann (2018) investigates the change in the product offering given an industry shock using a structural model. Assessing the bailout schemes provided to the auto industry in 2009, he finds that the ability to adjust vehicle production impacts firms operating results substantially. Pandolfi (2022) addresses the design of an optimal rescue mechanism for banks considering the availability of bail-in instruments alongside bailouts. He finds that, in the presence of low moral hazard and a liquidation option, the optimal policy is a combination of recapitalization (bail-in) and taxpayers' money from a bailout.

1.3. *Contribution*

Given the relatively limited literature that could shed light on the implications of financial aid packages on competition in network-based industries, this research develops an applied game-theoretic model to investigate the equilibrium outcome of the aviation transport market, when competition may be distorted by government bailout mechanisms. Specifically, we develop a single-stage, game-theoretic framework in which governments rescue airlines by offering different forms of financial aid. Carriers subsequently compete through a market share model and maximise their best response function. Airline decision variables include the number of aircraft operated, service frequency and average airfares for both business and economy class passengers per origin-destination served. We solve the game iteratively until we find the transport equilibrium outcome. Then we estimate social welfare by summing consumer, producer and government surpluses. Consequently, we investigate the implications of varying types of bailouts on overall welfare. Since different bailout schemes were provided to competing airlines, this raises the question as to whether the competitive equilibria have been distorted.

To the best of our knowledge, the model presented in this paper is the first to investigate the effect of government bailouts on airline competition by adopting a game-theoretic approach. In this sense, our work contributes to and enriches the literature on applied game-theoretic methodology. The insights provided by this research and the model we develop could guide policymakers in taking more consistent ex-ante decisions by predicting their impact on the entire industry. Moreover, we introduce into the modelling process the strategic decisions for an airline to potentially ground part of its fleet in order to reduce operating expenditures in a period of financial distress. This element of novelty allows us to examine competitive interactions that deviate from the traditional ”business as usual” scenario. Our results shed light on the competitive implications of the uncoordinated responses enacted by the European Union with respect to the Covid-19 outbreak. Finally, the insights provided by this research could be relevant to other distressed sectors characterized by the presence of multiple, competing firms that interact through a network structure. In particular, this approach could be applied ex-ante to a single firm in order to test the effectiveness of potential bailout schemes, independent of the status of the specific industry. Consequently, it is possible to obtain insights on any competitive distortions caused by the state aid mechanism, whether offered to a specific firm or a market-wide systemic bailout.

The plan of the paper is as follows. Section 2 develops the model framework and solution method. In Section 3 we present the data and numerical results of the model applied to the European aviation market

Table 1
Notation.

Sets and Indices	
$\mathscr{A}$	Set of airlines; indexed by a
$\mathscr{H}$	Set of flight types (i.e short-haul and long-haul); indexed by h
$\mathscr{K}$	Set of legs served by airline a in the itinerary from i to j for flight type h; indexed by k^h
$\mathscr{N}$	Set of airports nodes; indexed by i, j
$\mathscr{S}$	Set of passenger types; indexed by s
Parameters	
B_a	Net present value of the bailout repayment for airline $a \in \mathscr{A}$
β_{0s}	Direct connection parameter in the utility function for passenger type $s \in \mathscr{S}$
β_{1s}	Frequency parameter in the utility function for passenger type $s \in \mathscr{S}$
β_{2s}	Airfare parameter in the utility function for passenger type $s \in \mathscr{S}$
β_{3s}	Travel time parameter in the utility function for passenger type $s \in \mathscr{S}$
C_k	Cost for airline $a \in \mathscr{A}$ to serve leg $k \in \mathscr{K}$ per km flown
c_h	Conversion parameter in the cost functions for flight type $h \in \mathscr{H}$ to translate \$ into €
d_{ijs}	Potential demand between nodes $i \in \mathscr{N}$ and $j \in \mathscr{N}$ for passenger type $s \in \mathscr{S}$
ϵ_{ijsa}	Random component of utility between nodes $i \in \mathscr{K}$ and $j \in \mathscr{K}$ for passenger type $s \in \mathscr{S}$ of airline $a \in \mathscr{A}$
$\bar{f}_h$	Average utilization frequency for flight type $h \in \mathscr{H}$
GCD_k	Great Circle Distance of leg $k \in \mathscr{K}$
$MCPF$	Marginal cost of public funds
ζ	Interest rate on loan
ϕ	Taxation on airline profits
r	Bailout discount rate
η_t	Government remuneration from equity increasing over time t
ρ	Government remuneration as dividends
S_k	Number of seats available on leg $k \in \mathscr{K}$
τ_{ija}	Travel time between $i \in \mathscr{N}$ and $j \in \mathscr{N}$ for airline $a \in \mathscr{A}$ in minutes
T	Year at which the aid is fully repaid
Decision variables	
$f_{k^h a}$	Service frequency on leg $k \in \mathscr{K}$ of type $h \in \mathscr{H}$ of airline $a \in \mathscr{A}$
p_{ijsa}	Fare set on itinerary from $i \in \mathscr{N}$ to $j \in \mathscr{N}$ per passenger type $s \in \mathscr{S}$ of airline $a \in \mathscr{A}$
F_{ha}	Fleet size deployed for flight type $h \in \mathscr{H}$ by airline $a \in \mathscr{A}$ (i.e. number of narrow and wide-body jets)
Auxiliary variables	
$MS_{ijsa}(f_{ka}, p_{ijsa})$	Market share from i to j per passenger type $s \in \mathscr{S}$ of airline $a \in \mathscr{A}$ as a function of frequency and airfare
$\psi(F_{ha})$	Size of aid as a function of fleet size for airline $a \in \mathscr{A}$
V_{ijsa}	Systematic component of utility between nodes $i \in \mathscr{N}$ to $j \in \mathscr{N}$ per passenger type $s \in \mathscr{S}$ of airline $a \in \mathscr{A}$
z_{ija}	Minimum frequency over an indirect itinerary from $i \in \mathscr{N}$ to $j \in \mathscr{N}$ for airline $a \in \mathscr{A}$

in light of the Covid-19 pandemic. Section 4 discusses the conclusions of our work and suggests potential future research directions.

2. Methodology

In this section, we develop a single-stage, dynamic, Nash game framework in which the companies maximize their profits given their network structure and the decisions of their competitors. We begin by defining the network typology. Then we discuss demand and specify the utility function of passengers, based on which we develop a market share model. Subsequently, we specify the airline cost functions and multiple, potential bailout repayment schemes. We combine these elements into a game theoretic framework, using a non-linear optimization algorithm, we solve the game iteratively. In Table 1 we define the notation used throughout the paper.

2.1. Network specifications

The network in our model, $G(\mathscr{N}, \mathscr{K})$, is based on two potential structures. The hub-and-spoke structure allows carriers to maintain an airport base, namely the hub, and directly connect airports as spokes. The point-to-point network fully connects all nodes in the airline's chosen network. With respect to supply, we make the following three assumptions. First, we assume that only one type of aircraft is employed per arc type k^h, according to long-haul (k^l) and short-haul (k^s) flights. Based on the Official Airline Guide (OAG) data, the legacy carriers use hub-spoke networks to serve both long and short-haul connections whereas the low-cost carriers serve short-haul alone on a fully connected network. Second, given the limited number of itineraries connecting through two or more stops, we assume that the number of arcs belonging to an itinerary is bounded to a maximum of two for all airlines. Under this network formulation, we model both direct and indirect itineraries. Third, the network structure is assumed to be static in that the airlines' choice of network typology does not change. This assumption prevents airlines from acquiring slots at additional airports to serve new routes, however, the solution may lead an airline to stop serving a connection by setting its frequency to zero.

2.2. Demand and market share functions

With respect to the demand side, we define potential passenger demand between origin and destination pairs (i,j) per type of passenger s, namely *business* or *economy*. In our model, travellers select their preferred alternative among carriers based on the assumption of utility maximisation. Following the discrete choice models proposed by McFadden et al. (1973) and developed further in Ben-Akiva & Lerman (1985), we specify the utility function U_{ijsa} as a composition of systematic V_{ijsa} and random ϵ_{ijsa} components. The systematic part of the alternative provided by airline a is defined, according to the type of passenger s, for each origin i and destination j pair depending on the itinerary specifications, as shown in Eq. (1).

$$\begin{aligned} V_{ijsa} \quad = \quad & \beta_{1s} ln(1 + min\{f_{k^{h'} a}\}) + \beta_{2s} p_{ijsa} + \beta_{3s} \tau_{ija}, \\ & \forall i,j \in \mathscr{N}, \ s \in \mathscr{S}, \end{aligned} \tag{1}$$

where

$$\mathscr{K}' = \left\{ k^{h'} \middle| k^{h'} \text{ are the legs composing itinerary } i,j \in \mathscr{N} \right\}$$

In the systematic utility function (Eq. (1)), β_{1s}, β_{2s} and β_{3s} are the parameters of the utility components, p_{ijsa} and $f_{k^{h'} a}$ are the airfare and service frequency, respectively, that carrier a sets per itinerary, and τ_{ija} represents the travel time in hours for the origin-destination connection. The use of these four elements in the definition of passenger utility functions captures the most important drivers in the decision process. As highlighted in Hansen (1990), the use of a natural logarithm to represent the utility component associated with frequency accounts for the marginal decrease in value related to additional flights. Furthermore, since the origin and destination airports may be linked through a one-stop connection over a hub, the minimum value of the service frequencies of the set of legs in the itinerary represents the bottleneck effect of a specific leg on the itinerary. The last two components of Eq. (1) are the dis-utilities induced by the airfare and by the travel time of airline a on the route connecting i to j. These are the variables most commonly applied in the game-theoretic literature (Cadarso, Vaze, Barnhart, & Marín, 2017; Hansen, 1990; Hansen & Liu, 2015). Additional variables could be included, such as takeoff and landing times and punctuality rates (Garrow, 2016; Mumbower, Garrow, & Higgins, 2014). However, the inclusion of such variables increases complexity and computational time accordingly. For the purpose of this research, a strategic analysis of the effect of multiple types of bailouts, this reduced form utility formulation should be sufficient to capture passenger behaviour and the airlines' corresponding best responses.

Given the specification of the passenger utility function, a market share model is calculated as a nested logit function (NL) over two nests, where one nest consists of all airlines serving demand on (i,j) and the other nest includes the no-fly option. The market share model is defined as shown in Eq. (2).

$$MS_{ijsa} = \frac{e^{V_{ijsa}/\mu_s}\left(\sum_{a' \in \mathscr{A}} e^{V_{ijsa'}/\mu_s}\right)^{\mu_s - 1}}{1 + \left(\sum_{a' \in \mathscr{A}} e^{V_{ijsa'}/\mu_s}\right)^{\mu_s}} \tag{2}$$

where a' includes the set of all airlines operating directly or indirectly on the route (i,j) and V_0 represents the utility when the passenger does not fly. The random components of the utility function are assumed to follow a Gumbel distribution and to be independent and identically distributed (i.i.d.). It is important to note that, given the formulation in Eq. (2), the market share values range from 0 to 1. Passengers may decide to not fly if the utility associated with the alternatives offered by the airlines is less attractive than that related to the decision not to fly. Consequently, the no-fly option choice represents the price elasticity of demand and prevents airlines from setting excessively high airfares. We assume that the no-fly option is characterised by a utility equal to zero. The sum of each market share will be less than or equal to 1. Formally:

$$0 \leq MS_{ijsa} \leq 1, \quad \forall i,j \in \mathscr{N}, \ s \in \mathscr{S} \tag{3}$$

$$\sum_{a' \in \mathscr{A}} MS_{ijsa'} \leq 1, \quad \forall i,j \in \mathscr{N}, \ s \in \mathscr{S} \tag{4}$$

2.3. Costs and bailout repayments

The costs incurred by carriers include both operating and fixed components. Swan & Adler (2006) found that direct operating costs may be expressed as a function of aircraft capacity and great circle distance, GCD_k, between the two airports connected by arc k^h. They propose two equations, one for short-haul flights, mainly operated by narrow-body aircraft, and one for wide-body movements, usually employed in long-haul arc connections. The cost functions are multiplied by two to take into account the round-trip nature of the flights. Moreover, we use a conversion parameter c_h to account for the currency conversion rate (from \$ to €) and update the functions to 2019 cost per available seat kilometre (CASK) values per flight type h. We account for low-cost carriers by halving the short-haul operating costs, based on 2019 airlines' financial reports data analyzed.

$$C_{k^s}^{legacy} = 2(GCD_{k^s} + 722)(S_{k^s} + 104)\$0.019c_s \tag{5}$$

$$C_{k^s}^{lcc} = (GCD_{k^s} + 722)(S_{k^s} + 104)\$0.019c_s \tag{6}$$

$$C_{k^l} = 2(GCD_{k^l} + 2200)(S_{k^l} + 211)\$0.0115c_l \tag{7}$$

where,

$$\mathscr{K}^s = \{k^s | k^s \text{ are the short-haul legs}\}$$

$$\mathscr{K}^l = \{k^l | k^l \text{ are the long-haul legs}\}$$

The airline industry suffered from a severe liquidity problem and inability to cover their fixed costs in March 2020 because governments prevented them from providing service. In the absence of a revenue stream, the bailouts provided the minimum necessary to ensure the ongoing viability of airlines to cover their existing debt repayments and fixed costs. However, once the crisis subsides, the airlines are left with the additional debt accrued, which is dependent on the bailout type offered and its size. Several types of bailout mechanisms were applied in order to rescue carriers. Consequently, depending on the type of assistance provided, a specific repayment scheme B_a is included in the airline's objective function. We model three repayment schemes, namely grants, loans and equity ownership. In the case of grants, no repayment is required. In the case of loans and equity instruments, the reimbursement from this intervention has been modelled as the net present value of the aid repayment scheme discounted by a rate of r. The interest rate ζ on the loan is set according to the repayment date. In the case of government intervention through equities, the remuneration and exit strategies are defined such that the beneficiary of the recapitalization is incentivized to repurchase the shares. This is achieved by setting a level of remuneration for the nominal investment that increases over time at an annual interest rate of η_t and an adequate government remuneration ρ in the form of dividends.[1] Given these characteristics, the net present value function of the bailout repayment scheme assumes one of the following forms:

$$B_a = \begin{cases} 0 & \Leftrightarrow \text{Grant} \\ \sum_{t=1}^{T} \frac{\psi(F_{ha})}{T} \frac{\zeta}{(1+r)^t} & \Leftrightarrow \text{Loan} \\ \sum_{t=1}^{T} \frac{\psi(F_{ha})}{T} \frac{\eta_t}{(1+r)^t} + \frac{\pi\rho}{(1+r)^T} & \Leftrightarrow \text{Equity} \end{cases} \tag{8}$$

where $\psi(F_{ha})$ is the size of the aid provided to the airline as a function of the fleet deployed when the airline is rescued through a loan or equity, and is assumed to remain constant, when a grant is received. Specifically, grants are generally provided to small-scale airlines characterized by a fleet composed of a few aircraft. Hence, any reduction in their fleet size will result in a suspension of most of their operations and a consequent airline default. T is the last period in which the carrier completes the bailout repayment (or defaults). A bankruptcy manifests in the case when the airline is not able to perform any operations and its profits turn negative. The instruments permitted by the European Commission and modelled in our framework, take into account the uncertainty caused by the pandemic whereby loans are expected to be returned within a shorter period of time as compared to equity. Specifically, loans were offered for six years whereas equity injections were substantially more expensive but permitted a restructuring process over eight or more years.

2.4. Mathematical formulation

The competitive airline industry is modelled as a Nash non-cooperative game in which carriers maximise their profits, given other airlines' best response functions, until the iterative solutions of the optimization problems converge to an equilibrium. Each airline's profit function assumes the form of revenue minus cost and the three decision variables are fleet size, flight frequencies and airfares. Given the cost function, bailout repayment scheme and nested market share model, the non-linear profit function assumes the following form:

$$\begin{aligned} \underset{p_{ijsa}, f_{ka}, F_{ha}}{Max} \ \pi_a \ = \ & \Bigg[\sum_{\substack{i,j \\ i \neq j}} \sum_{s} MS_{ijsa}\left(f_{k^h a}, p_{ijsa}\right) d_{ijs} p_{ijsa} \\ & - \sum_{k^h} C_{k^h}(GCD_{k^h}, S_{k^h}) f_{k^h a}\Bigg] \frac{(1-\phi)}{(1+r)^T} - B_a(F_{ha}) \end{aligned} \tag{9}$$

where MS_{ijsa} is the market share for an itinerary connecting i to j for passenger type s operated by airline a; d_{ijs} is the potential demand observed between i and j per passenger type s; S_{k^h} is the aircraft seat capacity on the k^h arc; and ϕ is the corporate taxation level on airline profits.

The objective function is subject to the constraints (10)–(17). All constraints are linear except for (10) and (13).

---

[1] Modelling market fluctuations during the period in which airlines buy back their equities is beyond the scope of this research. Consequently, we assume that holding equities of airlines, governments are remunerated only through interest rates and dividends.

Algorithm 1 Solve the game

```
Start
Initialise values of competitors' decision variables and their network characteristics
$condition \leftarrow false$
$iterator \leftarrow 1$
Create an empty list $candidate$ to store possible solutions
while $condition == false$ do:
cycle:
    for $a$ in $airline$ do:
        Solve the mathematical program for $a$ using $IPOPT$
        Store solution in $candidate$
        Airline $a$ moves to set of competitors while airline $a+1$ leaves
    if $(iterator > 1)$ & $(candidate[iterator] - candidate[iterator-1] \leq threshold)$ then:
        $condition \leftarrow true$
        $solution \leftarrow candidate[iterator]$
    $iterator \leftarrow iterator + 1$
return $solution$
Stop
```

$$MS_{ijsa} = \frac{e^{V_{ijsa}/\mu_s}\left(\sum_{a^{'}\in\mathscr{A}} e^{V_{ijsa^{'}}/\mu_s}\right)^{\mu_s - 1}}{1 + \left(\sum_{a^{'}\in\mathscr{A}} e^{V_{ijsa^{'}}/\mu_s}\right)^{\mu_s}}, \ \ \forall\, i,j \in \mathscr{N},\ s \in \mathscr{S} \tag{10}$$

$$z_{ija} \leq f_{\omega^{'}a}, \ \ \forall\, i,j \in \mathscr{N}, \omega^{'} \in \Omega^{'} \tag{11}$$

$$z_{ija} \leq f_{\omega^{''}a}, \ \ \forall\, i,j \in \mathscr{N}, \omega^{''} \in \Omega^{''} \tag{12}$$

$$\sum_{i^{'},j^{'}\in\mathscr{N}^{'}} \sum_{s} d_{i^{'}j^{'}s} MS_{i^{'}j^{'}sa} \leq S_{k^h} f_{k^h a}, \ \ \forall\, k^h \in \mathscr{K} \tag{13}$$

$$\sum_{k^h} f_{k^h a} \leq \overline{f_h} F_{ha}, \ \ \forall\, h \in \mathscr{H} \tag{14}$$

$$f_{k^h a} \geq 0, \ \ \forall\, k^h \in \mathscr{K} \tag{15}$$

$$p_{ijsa} \geq 0, \ \ \forall\, i,j \in \mathscr{N},\ s \in \mathscr{S} \tag{16}$$

$$F_{ha} \geq 0, \ \ \forall\, h \in \mathscr{H} \tag{17}$$

where,

$\mathscr{N}^{'} = \{i^{'},j^{'} | i^{'},j^{'}$ are the itineraries passing through arc $k^h\}$

$\Omega^{'} = \{\omega^{'} | \omega^{'}$ is the first arc of the itinerary $i,j \in \mathscr{N}\}$

$\Omega^{''} = \{\omega^{''} | \omega^{''}$ is the second arc of the itinerary $i,j \in \mathscr{N}\}$

Constraint (10) defines the market share following the nested formulation described in Eq. (2). Since the passenger utility is not a continuous function due to the presence of a minimum, we overcome this discontinuity by linearising the functions using constraints (11)-(12). Eq. (13) represents the constraint of the aircraft capacity. This bound ensures that the demand served by airlines never exceeds the seat availability offered on the leg. Eq. (14) specifies that each airline's service frequency is bounded by their fleet size F_{ha} and the average utilization rate $\overline{f_h}$ according to flight type h.

Constraints (15)–(17) specify the domain of the decision variables. Given the strategic nature of this analysis, we assume that all decision variables are continuous, which is clearly a simplification, in order to reduce complexity.

The resulting program, despite the linearisation enforced through constraints (11)-(12), is still highly non-linear in its objective function and constraints due to the market share model. To find a solution to the non-linear programming maximisation problem, a primal-dual, interior point algorithm with a filter line search method is applied. This procedure, proposed by Wächter & Biegler (2006) and implemented in the *IPOPT* routine, solves nonlinear programs with double differentiable objectives and constraints. We note that the optimal solution found through this algorithm may converge to a local rather than global optimum. To guarantee the robustness of the results obtained, we perform sensitivity analyses by initialising the program with different starting control sequences.

2.5. *Game-theoretic competition*

The mathematical program in Eqs. (9)–(17) is embedded into a single-stage dynamic game, where airlines compete given their network structure. The set of players is represented by all airlines operating in the market. Carriers may decide to stop serving existing connections by setting a frequency equal to zero but are not permitted to change the nodes they serve. The Nash equilibrium is obtained as a result of an iterative algorithm, where the mathematical program is solved sequentially for each player of the game and where the values of the decision variables of each iteration are used as input for the next iteration. A cycle is defined when a solution of the mathematical program has been computed for all airlines. The process ends when a Nash equilibrium is found in which no player has the incentive to deviate from his best response to the other players' strategies. The algorithm stops when the value of the objective function for each airline changes by less than 1% across two consecutive iterations. The pseudo-code of the solution process is described in Algorithm 1.

In this framework, the focus is entirely devoted to airlines, as they are the only players considered in the game. However, since the service frequency, airfares and itinerary characteristics (directness of the flight and elapsed travel time) determine the travellers' utility, passengers play an indirect role in the game. The government sets the rules of the bailout at the beginning of the game and receives remuneration (or not in the case of grants or should the airline enter bankruptcy if the profits are non-positive) according to the scheme chosen.

2.6. *Social welfare analysis*

To analyse the impacts of airline bailouts on overall social welfare, we define the welfare function as the sum of consumer, producer and government surpluses. Formally, the welfare function is expressed as in Eq. (18).

Table 2
TFEU interest rates on loan.

Time since loan received	1 year	2–3 years	4–6 years
Interest rate	0.5%	1.0%	2.0%

Table 3
TFEU interest rate on equity.

Time since equity received	1 year	2–3 years	4–5 years	6–7 years	8 or more years
Interest rate	4.5%	5.5%	7.0%	9.0%	9.5%

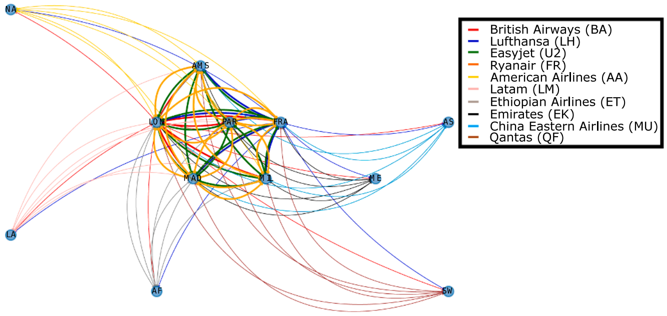

Fig. 1. 12-node network with 10 competing airlines.

Table 4
Cities, macro-regions and carriers in our network.

City/Macro-region	City/Region code	Hub carrier (IATA code)	LCC operating (IATA code)
London	LON	British Airways (BA)	Ryanair (FR), Easyjet (U2)
Frankfurt	FRA	Lufthansa (LH)	
Amsterdam	AMS	-	
Madrid	MAD	-	
Milan	MIL	-	
Paris	PAR	-	
North America	NA	American Airlines (AA)	-
Latin America	LA	Latam(LA)	-
Africa	AF	Ethiopian Airlines (ET)	-
Middle East	ME	Emirates (EK)	-
Asia	AS	China Eastern Airlines (MU)	-
Oceania	SW	Qantas (QF)	-

$$
\begin{aligned}
W \quad = \quad & \sum_a \pi_a + \sum_{i,j,s} d_{ijs} \frac{1}{-\beta_{2s}\mu_s} ln\left(\left(\sum_{a^{'} \in \mathscr{A}} e^{V_{ijsa^{'}}}\right)^{\mu_s} + e^{V_0}\right) \\
& + \sum_a \left(\phi \pi^{'}_a + B_a\right) MCPF
\end{aligned}
\tag{18}
$$

The first term represents airline profits, the second is the surplus of travellers derived from the logsum of the nested logit function (Small & Rosen, 1981) and the last term represents the government income from taxation and bailout remuneration. $\pi^{'}_a$ is the airline profit net of bailout repayment and *MCPF* is the marginal cost of public funds.

3. European case study

In this section, we first discuss the bailout scheme structure approved by the European Commission, then the airlines' network topology, the data analysed to set the values of the parameters and finally, the results of the analysis. The structure of the results is based on multiple scenarios in which different European Member States invest in the airlines according to the multiple bailout schemes in order to understand their impact on the new competitive equilibria outcomes.

3.1. Bailout schemes during Covid-19

To respond to the severe impact caused by the Covid pandemic, governments have provided aid packages that support firms during liquidity shortages. The two main bailout schemes were the CARES Act (116th Congress, 2020) in the US and the Temporary Framework for the European Union (TFEU) (European Commission, 2021). Since our interest is focused on the European aviation market, we describe the TFEU in detail. Airline bailouts approved under this scheme are reported in Appendix A according to the Member State. Given the limited resources available to the European Union, the Member States individually chose the support measure and its financial magnitude, following the rules set by the European Commission. The TFEU suggests several ways to bail out firms facing the risk of bankruptcy: providing aid in the form of a direct grant, guarantees or subsidised public loans, equity injection, deferral of taxes, hybrid instruments and state recapitalisation. In this research, we focus on the three most prevalent instruments, namely grants, loans and equity investments.

Direct grants, consisting of a lump sum transfer without any repayment, represent the easiest and fastest support measures for firms. Loan-based instruments are designed with a horizon of a maximum of six years from the date that the financial injection is received. The aid is subject to an increasing interest rate over time, depending on the repayment period as reported in Table 2.

Government support in the form of equity or hybrid instruments is undertaken through the purchase of newly issued shares, which (re)introduces the State as a firm shareholder. We model only equity-based schemes and do not include hybrid instruments due to their specificity. The interest rate of the equity instrument is increasing over time as shown in Table 3. Under this setting, firms are allowed to buy back their shares from the State at any time, repaying the initial nominal investment plus the relevant annual interest rate and paying dividends only in relation to the State.

Although the cost of equity is higher than that of the loan, it does provide the airline with a longer time frame to repay the investment. Given the fact that at the beginning of a crisis, there is a lot of uncertainty as to the length of time required to return to business as usual, this is an advantage over the alternative bailout schemes.

3.2. Network and players

The model proposed in Section 2 is tested on a real-world scaled network served by ten competing airlines, over a 12-node network, as depicted in Fig. 1. Four European carriers are modelled including two legacy carriers and two low-cost carriers. The remaining six airlines are non-European and fly from their respective hubs to the six European nodes. This is clearly a simplification of the market hence we define all non-European nodes as "macro-region". A macro-region is defined as a representative market capturing the average demand from and to the major European cities. In particular, we define six macro-regions outside Europe, *North America, Latin America, Africa, Middle East, Asia* and *Oceania* in order to capture the connections between each of the major European cities and other possible destinations (origins). Table 4 summarises the airlines and nodes in the network. Accordingly, both long-haul and short-haul competition is considered. The networks depicted in Fig. 1 include both hub-and-spoke and point-to-point networks, where adjacent nodes are connected by numbered route arcs. We include British Airways with a hub in London and Lufthansa with a hub in Frankfurt to represent the legacy carriers in the case study. We assume that Ryanair and Easyjet serve a fully connected European network, both representing low-cost carriers. To locate the node belonging to a macro-region and compute the distance and travel time between the other nodes, we use the region centroid. We note that the network allows both

Table 5
Nested logit parameters (Adler et al., 2010).[a]

	Continental		Intercontinental	
	Economy	Business	Economy	Business
Service frequency (β_{1s})	0.89	1.16	0.356	0.928
Airfare (β_{2s})	− 0.01	− 0.004	− 0.004	− 0.008
Travel time (β_{3s})	− 0.02	− 0.015	− 0.004	− 0.01
Inter-nest heterogeneity (μ_s)	0.68	0.77		

[a] We divide by half the airfare coefficient for business intercontinental passengers in order to provide fares in line with real market values.

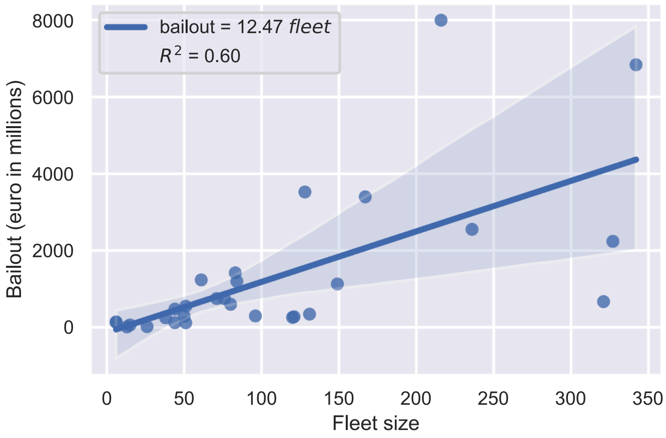

Fig. 2. OLS regression of bailout magnitude on airlines' fleet size.

direct and indirect connections between each node pair. For the case study, we select the largest airlines belonging to the macro-regions and the European Member States. The aim is to minimize the size of the game for computational simplicity but ensure a sufficiently rich description of the market so that conclusions may be drawn.

3.3. Parameters

Here we define values for the parameters used in our model. First, we discuss the airlines, subsequently demand and finally the aid packages. We describe the values used for the three bailout types and the time horizon for the repayment.

The distance between two nodes, GCD_k, is computed as the great circle distance between two nodes in kilometres. In a similar fashion, we compute the elapsed travel time in hours. We assume that a wide-body aircraft serves a maximum of 13 flights in a representative week, leaving time for maintenance. In a similar manner, we assume that two short-haul connections are possible daily, resulting in an average of 27 flights per week for a short-haul, narrow-body aircraft. We define the seat capacity according to two reference aircraft, one for each type of operation. Specifically, we assume that short-haul flights are operated using a Boeing 737 aircraft configured to accommodate 180 seats while long-haul connections are operated using a Boeing 777 accommodating 375 passengers. The conversion parameter c_h converts the currency in the cost function to Euros and calibrates the parameters in Eqs. (5)–(7) to reflect the CASK values reported in the 2019 airlines' performance reports. In the cost function $c_s = 0.8$ for short-haul flights and $c_l = 1.8$ for long-haul flights.

Demand levels are computed using 2019 traffic data from OAG. Due to the highly seasonal trend in the pattern of aviation traffic, we calculate the demand as the average number of passengers during the weeks of February and August, the off-peak and peak month, respectively. Given the predominant nature of flights as round-trips, demand is assumed to be symmetric between each origin and destination pair. The nodes in our network cover 10% of the demand served by the selected airlines. A load factor of 80% is assumed for both business and economy class passengers for legacy carriers while this value is increased to 90% for LCCs in order to represent the higher load factors that characterize these airlines. The coefficient values in the nested logit model are those estimated in Adler et al. (2010) and are reported in Table 5, according to two types of passengers s and whether the flight is continental or intercontinental.

The magnitude of the aid is a function of the size of the airline. Consequently, the size of the bailout is estimated linearly, through an ordinary least squares (OLS) regression, using airlines' fleet size as a proxy for the carrier size. The regression is presented in Fig. 2 and the specific details in Appendix A. The magnitude of the bailouts corresponds to an average of € 12.47 million per aircraft. The interest rate for loans, ζ, is set at 2% and for equity, η_t, increasing over time up to 9%, both consistent with the rules of the European Commission (2021). The time horizon T for the analysis is set to six years, in line with most of the industry forecasts (Airbus, 2022; ICAO, 2020). We assume that airline demand will completely recover to pre-Covid-19 levels by 2025 in line with expectations (Airbus, 2022). The corporate tax rate on airline profits is assumed to be 20.6%, as specified in the OECD (2020) report. The discount rate r of the bailout is defined according to the DG Competition (2008) report, and is set at a 2% level.

3.4. Results

We apply our model to seven different scenarios characterized by combinations of bailouts in order to explore the effects of the mix of bailout schemes on airline competition and social welfare. Scenarios are reported in Table 6.

Without state aid, the European airlines would probably have not survived the pandemic, hence we focus on scenarios in which carriers receive a bailout. Many of the airlines that did not receive bailouts either went bankrupt or filed for Chapter 11 protection (Avianca, Latam, Air

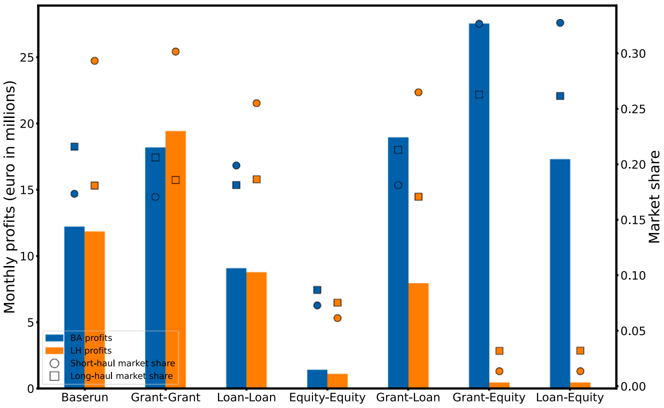

Fig. 3. European legacy carriers' weekly profits and market share.

Table 6
Bailout composition in scenario analysis.

	Baserun	Grant-Grant	Loan-Loan	Equity-Equity	Grant-Loan	Grant-Equity	Loan-Equity
British Airways	-	Grant	Loan	Equity	Grant	Grant	Loan
Lufthansa	-	Grant	Loan	Equity	Loan	Equity	Equity

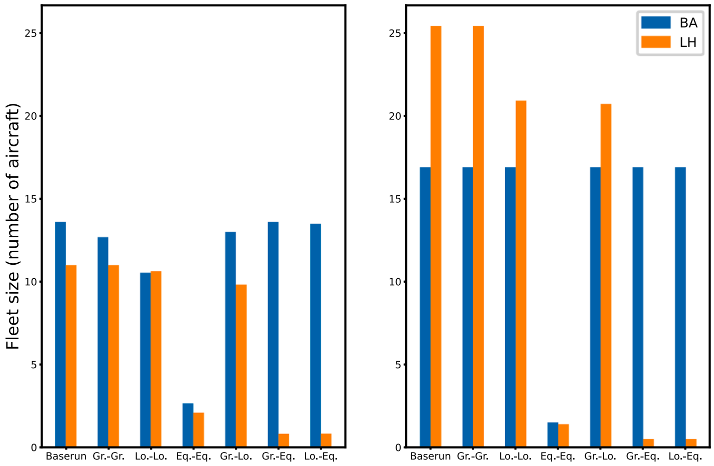

Fig. 4. Long-haul fleet (left) and short-haul (right) for the two European legacy carriers.

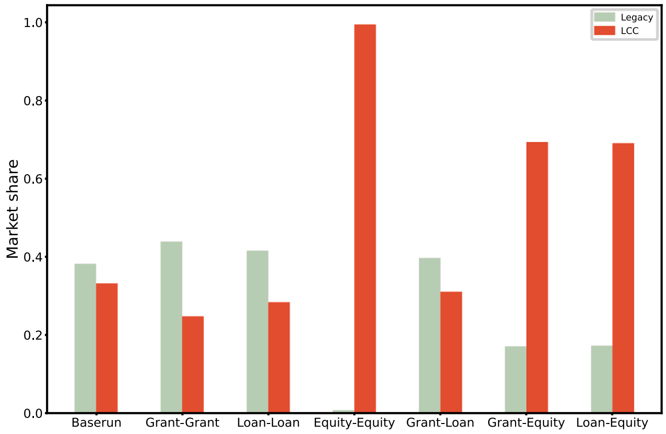

Fig. 5. Market share of legacy and LCC carriers in the short-haul markets.

Italy, Flybe, etc.). The pandemic caused governments to intervene in the market, which, in turn, forced airlines to stop operations in most cases. Specifically, we show how the two main European legacy carriers, British Airways (BA) and Lufthansa (LH), compete between themselves and all other carriers, under different bailout provisions. LCCs and non-European legacy carriers also received bailouts which have been included in all scenarios except the *Baserun*. Figs. 3,4,5 and Table 8 present the results in terms of airline profits, airfares, service frequency and fleet size under the different scenarios. The B*aserun* scenario validates the model and parameters based on 2019 values, which was the last year available prior to the pandemic. Subsequently, we analyse the impact of bailout combinations on the competitive equilibria outcome. We initialize our algorithm using 50 different randomly generated control sequences and we find consistent results across all cases (Table 7).

The scenario in which both legacy European operators receive a bailout through a grant, the *Grant-Grant* case, exhibits an increase in airline profits over the *Baserun* because the fiscal stimulus is not subject to any repayment mechanism. This scenario resembles the structure of the baserun case and slightly alters the competition in the industry since both airlines receive the same type of bailout, Lufthansa increases its operations at the expense of British Airways and both airlines increase profits thanks to the government stimulus. Since we do not model the pandemic itself, the increase in profits is artificial and in the real world would simply cover the losses caused during the cessation of service.

The scenario in which both airlines receive a loan, the *Loan-Loan* case, shows that both carriers are less profitable than the Baserun case. This result is caused by a decrease in service frequencies due to the decision to ground part of their fleet in order to reduce operating

Table 7
Average *Baserun* values and maximum percentage variation (in brackets) of objective function and decision variables of BA in 50 randomly generated control sequences.

Profits (€ m)	Fares				Frequencies	Fleet	
	Long-haul		Short-haul			Long-haul	Short-haul
	Business	Economy	Business	Economy			
12.2 (0.0025)	2,051 (0.0042)	616 (0.0001)	385 (0.0003)	192 (0.0005)	57 (0.0005)	14 (0.0008)	17 (0.0006)

Table 8
Percentage variation in average airfares compared to Baserun.

	Baserun (€ m)		Grant-Grant (%)		Loan-Loan (%)		Equity-Equity (%)		Grant-Loan (%)		Grant-Equity (%)		Loan-Equity (%)	
Long haul	BA	LH	BA	LH	BA	LH	BA	LH	BA	LH	BA	LH	BA	LH
Business	2,051	1,995	2	2	3	5	22	25	3	2	27	21	27	21
Economy	616	647	8	5	18	10	104	98	9	9	26	107	27	107
Short haul	BA	LH	BA	LH	BA	LH	BA	LH	BA	LH	BA	LH	BA	LH
Business	385	421	21	18	22	16	105	92	26	16	136	78	136	78
Economy	192	168	61	66	54	72	299	386	67	72	89	382	89	382

Table 9
Variation in the social welfare components.

	Baserun (€ m)	Grant-Grant (%)	Loan-Loan (%)	Equity-Equity (%)	Grant-Loan (%)	Grant-Equity (%)	Loan-Equity (%)
Airline surplus	25	52	– 25	– 73	11	19	– 21
Consumer surplus	5	– 19	– 19	– 34	– 19	– 33	– 33
Government surplus	7	– 28	312	234	146	67	238
Social welfare	38	27	39	– 10	32	21	26

expenses. Given this decision, BA changes its strategy and focuses more on the short-haul market, reducing LH shares in European connections.

In the *Equity-Equity* setting, both European legacy carriers are subject to the buyback of their shares and repayment of interest to the government. In this scenario, airlines report a severe reduction in profits of more than 85%. To contain costs, the two carriers ground most of their fleet, resulting in a sharp decrease in service frequency. In this scenario, airlines increase fares in both short and long-haul markets. These combined decisions show that airlines tend to focus more on the less competitive long-haul markets, giving up market share on intra-continental routes when subjected to severe financial distress. It would appear that loan provision is relatively preferable for both airlines as compared to equity, although this depends on the assumption that the bailouts will be repaid within six years. If this timeframe were to prove insufficient, then the more expensive but longer-term equity schemes might prove necessary.

The results suggest that government aid in the form of a grant, when the competing legacy carrier is subject to the repayment of a loan, as in the scenario *Grant-Loan*, distorts the competitive outcome. The airline given a loan is penalised compared to the airline receiving a grant and is forced to reduce expenditures by decreasing the number of flights offered and reducing the size of its fleet. As a result of this distortion, the carrier subject to a loan increases the airfare in both short and long-haul markets in an attempt to increase revenues. The unbalanced bailout setting leads all carriers to acquire market shares at the expense of the airline that receives the loan.

A similar result, but greater in magnitude, is obtained when one of the two European legacy airlines receives a bailout in the form of a grant and the competitor is financed using equity instruments as in the *Grant-Equity* scenario. This combination of bailouts is the most competition-distorting, leading to a severe contraction in profits and fleet size and an increase in airfares in the more competitive short-haul market for the carrier subject to the equity burden. The distortion results in the disappearance of the equity-financed carrier from the European short-haul market.

In the scenario *Loan-Equity*, which most closely resembles the British Airways - Lufthansa markets, the carrier receiving a loan takes advantage of the better financial position and exploits market power with respect to the recapitalised airline. The partially renationalized airline is forced to ground most of its fleet in order to contain expenditures and decreases service frequency accordingly. As in the previous scenario, the recapitalised airline increases short-haul and long-haul fares. The carrier under greater distress thus continues to compete on the more profitable inter-continental markets, giving up most of the continental operations.

The comparison between European legacy airlines and LCCs, shown in Fig. 5, highlights the impact of the mixed-use of bailout schemes on the subsequent competitive equilibria outcome on the intra-European market. This is motivated by the financial burden on the legacy carriers of repaying the bailout since they were already under competitive pressure before the exogenous pandemic shock. Given that the LCCs received small loans, their market share may grow from 35% prior to the pandemic to above 60% in *loan-equity* scenario.

Once the equilibria have been computed for the seven scenarios, we evaluate the passengers, airlines and government surpluses and the overall social welfare, as shown in Eq. (18). Specifically, we compare the six scenarios in which a bailout is provided to airlines against the Baserun case in the absence of any scheme. We note that during the Covid-19 pandemic, grant stimuli have been provided to small carriers alone and are of a marginal magnitude compared to the loans and equity offered to legacy airlines (Appendix A). Due to the onerous nature of this type of aid on taxpayers, we consider grants to be an infeasible mechanism for bailing out large airlines. Table 9 presents the variation across the three welfare components as a function of the scenario analyzed.

Our analysis suggests that airline surplus increases in all scenarios involving the use of a grant. This is especially visible in the scenario in which both airlines receive a grant, *Grant-Grant*, in which carriers benefit from government intervention and increase their profits by up to 52%. Conversely, airlines are worse off when subject to the repayment of interest on the bailout, particularly when they are subject to the repayment of an equity scheme. In the scenario *Equity-Equity*, in which the highest variation occurs, airlines are worse off by 73% compared to the Baserun case. Our results suggest that bailing out carriers results in a loss of welfare for passengers too. This downturn in surplus is driven by the increases in airfares and by the reductions in service frequencies, impacting the perceived utility of flying. This reduction is particularly severe in the *Equity* scenarios, suggesting a reduction of 33% in passenger surplus.

The government surplus is positive in all the intervention scenarios with the exception of the case when both airlines are rescued through a grant (*Grant-Grant*) and hence are not subject to any repayment. Notably, our analysis suggests that the most profitable scenario for the government is the renationalization of the airline, enabling government participation in airline dividends and financial inflows through interest rate repayment. This scenario results in a 234% increase in surplus compared to the Baserun case. Our welfare analysis suggests that the most distorting scenario is that in which both airlines are renationalized through equity, reaching a loss in welfare up to 13% compared with the Baserun scenario. However, the airlines are likely to survive thus ensuring the repayment of the taxpayers' bailouts.

In summation, our analysis suggests that the more preferable intervention, which also ensures a level playing field, may be to provide loans to all carriers. This intervention results in a social welfare improvement of 39% compared to the Baserun scenario, which is mainly driven by the increase in government surplus given the repayment of loan interests. However, this overall increase also includes decreases in both consumer and airline surplus. In Fig. B.1, reported in Appendix B, we present sensitivity analyses showing the impact on social welfare of changes in the demand, frequency utility coefficient and airfare disutility coefficient. The changes in social welfare are consistent with the results of our analysis across all scenarios. It is interesting to note that social welfare is particularly sensitive to variations in the airfare coefficient. A small reduction in the airfare utility coefficient increases more than proportionally both consumer and airline surpluses. Conversely, a small increase induces a large contraction in welfare, mainly due to a decline in consumer surplus resulting from a reduction in passenger numbers. Aside from the increase in social welfare resulting from the repayment of loan bailouts, it is worthwhile noting how the provisions of loans instead of equities toward airlines, provide BA with a significant competitive advantage over LH. At the beginning of the pandemic, governments were required to choose between providing financial resources to industries strongly impacted by the exogenous shock or allowing the companies to enter bankruptcy. This form of insurance balances the interests of private firms with the general public, which is complicated by the inability to predict the date and duration of the exogenous shock.

Overall, sharing the risks of exogenous and unpredictable shocks would appear to be preferable provided the companies survive and repay the interest on their debt. The results of our model appear to be reflected in the real world, although it may still be too early to predict the final outcome (Darroch, Mathurin, & Campbell, 2022).

4. Conclusions and future directions

In this research, we develop a game-theoretic model capable of representing the competition between airlines before and after receiving government aid packages. In our model formulation, not only do carriers strategically set service frequency and airfares, but they also select the number of aircraft to operate. We apply our model to the recent Covid-19 outbreak in order to assess the potential market distortions induced by state aid. We develop an algorithm that estimates the Nash equilibria across seven scenarios, characterized by different combinations of bailouts.

Our analysis suggests that the airline industry has been severely affected by the uncoordinated provision of state aid, leading to an unlevel playing field for the European carriers and a likely drop in passenger and airline surpluses. In particular, we compare two airlines of similar size prior to the pandemic and show that unequal bailout policies will likely disrupt the profitability and structure of the two carriers. Successively, results have shown that it is possible to achieve a socially preferable outcome through a coordinated and homogeneous bailout mechanism across the Member States. Our findings are consistent with the results of the analysis of Bianchi (2016). We demonstrate that the European Commission would have been more efficient had it required all carrier bailouts to be in the form of loans hence limiting the negative effects on social welfare. In our case study, we note that Ryanair received a much smaller loan relative to Easyjet and the legacy carriers, enabling the ultra low cost airline to increase market share substantially. This highlights how the bailouts, both in form and in quantity are likely to impact transport equilibria and the competitive playing field. As Kahn (1988) and Rose (2012) emphasised, the deregulation of the airline industry has been a success in terms of efficiency and competition. The inefficiencies we highlight are the result of coordination failures between governments.

Future directions for research consist of several options since this paper represents the first attempt to model the bailout in the airline industry in a competitive game-theoretic network environment. It could be interesting to evaluate the effects that government involvement, as an airline shareholder, may have on carrier decisions to act in the country's interest, departing from the assumed profit maximisation strategy paradigm. It would also be interesting to address the impact of bailouts on the strategic behaviour of carriers within alliances and the possible reshaping of interline and codeshare agreements. Another interesting research question would be to assess the impact of the market equilibrium on the aviation supply chain, including airports and air navigation service providers.

Declaration of Competing Interest

None

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Appendix A

Government support for airlines in Europe

Country	Airline	Aid size (€ m)	Type of aid
Austria	Austrian Airlines (LH group)	450	Grant and Loan
Austria	Condor	550	Loan
Belgium	Brussels Airlines (LH group)	290	Loan
Croatia	Croatia Airlines	11.7	Grant
Estonia	Nordica	30	Equity
Latvia	Air Baltic	250	Equity
Finland	Finnair	1,237	Equity
France	Air France	8,000	Loan and Equity
France	Corsair	141	Grant
Germany	Lufthansa (LH group)	6,840	Loan and Equity
Germany	TUI	3,526	Loan
Greece	Aegean	120	Grant
Italy	Alitalia	297	Grant
Netherland	KLM	3,400	Loan
Norway	Norwegian	277	Loan
Norway	Wideroe	121	Loan
Poland	Lot	750	Loan and Equity
Portugal	SATA	133	Loan
Portugal	TAP	1,200	Loan
Romania	Blue Air	62	Loan
Romania	TAROM	19.3	Loan
Spain	Air Europa	475	Not confirmed
Spain	Iberia (BA group)	750	Loan
Spain	Vueling (BA group)	260	Loan
Sweden, Denmark	SAS	1,130	Equity
Switzerland	Swiss (LH group)	1,420	Loan
UK	British Airways (BA group)	2,553	Loan
UK	Easyjet	2,240	Loan
UK	Ryanair	670	Loan
UK	Wizz air	344	Loan

Source: self-collected from European Commission (2021)

Appendix B

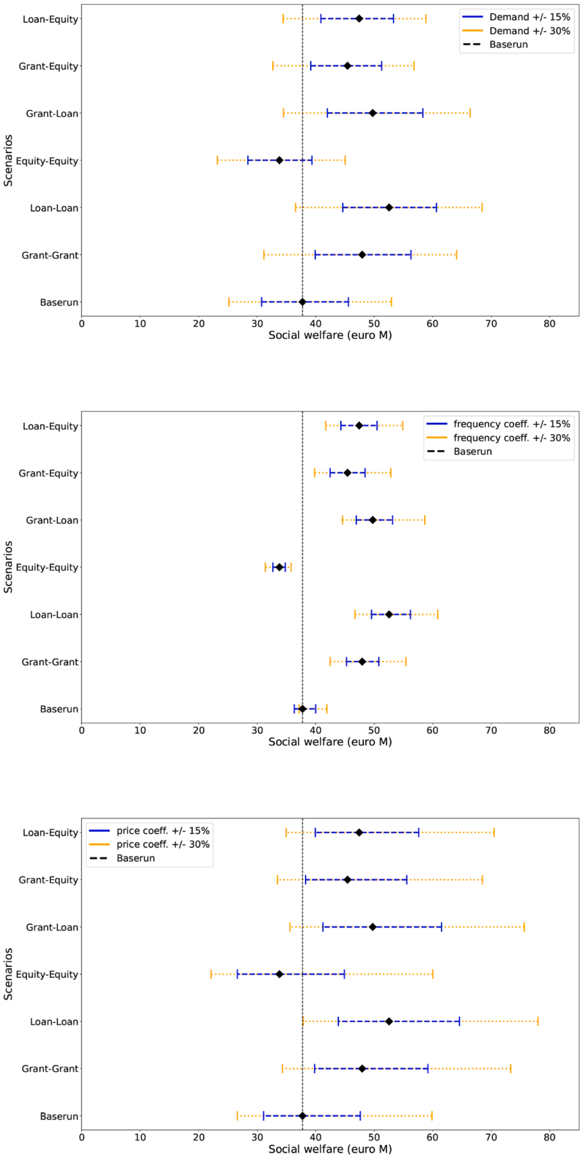

Fig. B.1. Percentage variation of social welfare for different model parameters.

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